CELESTIAL FRONTIERS*

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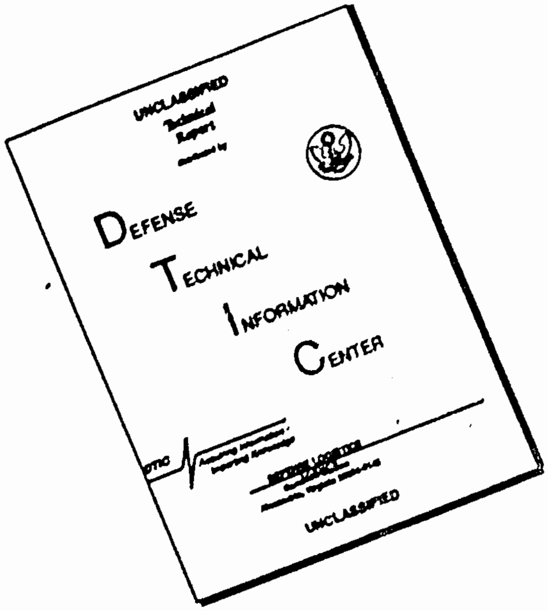

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Material on which this paper is based was developed during the period the author was on the staff of the National Aeronautics and Space Administration.

CELESTIAL FRONTIERS

In accepting the honor you have given me by extending the invitation to address this joint meeting of the American Congress on Surveying and Mapping, and the American Society of Photogrammetry, I have selected the title "Celestial Frontiers," since it is well known that surveyors and mappers are more than casually acquainted with the celestial sphere. Many of you are knowledgeable of, and indeed some have made important contributions to the science of celestial mechanics, as well as to the practical applications of astronomy to surveying and navigation.

Perhaps I should assure you at the outset that I do not intend to delve into the theological or the more abstract philosophical connotations which the title of this paper might suggest, except to say that I am mindful of the growing import of space developments on the expanding sphere of human relations.

As an engineer, however, I do intend to say first something about what my professional group owes to yours, secondly what rate of progress we might reasonably expect in probing our celestial frontier, and thirdly remind you of the opportunities -- the challenges -- to both your profession and mine for contributing even more in the future than we have in the past to our aero/space developments.

On the first point -- my own pleasant surprise at the truly remarkable precision achieved in the knowledge of the size and shape of the earth by your profession well before the time we aeronautical and space engineers seriously entered the field, is only typical of that shared by all of us who like to class ourselves in that now honorable, but small group of FSBS's (For Space Before Sputnik). We had the pleasure of discovering

and becoming well acquainted with the works of such stalwarts as Moulton, Jordan, Helmert, Bessel, Clark, and their modern counterparts. In developing our earliest plans for space activities we realized the great debt we owe to your profession, and I am happy to record it here. More specifically, the achievements of geodesists, astronomers, and surveyors based on careful work painstakingly accomplished over the past century have given us, as space planners, the sound basis for reliable and precise orbital calculations and control. Without this substantial foundation even some of the first contributions of satellites to man's store of scientific information, to his enhanced understanding of the size and shape of the earth, would not have been possible. Yet, just as the foundations of great engineering structures are often overshadowed or hidden by the spectacular buildings they support so also does the dependable geodetic foundation for our space needs tend to be hidden.

For example, the 75th meridian tracking "fence" extending from Blossom Point, Maryland, to Antofagasta, Chile, was promptly and accurately established through the good offices of the Inter-American Geodetic Survey, a clear first in the field of international cooperation in space activities. This Minitrack "fence" today forms an integral and vital part of our growing world-wide space tracking net and was made possible by the work of the Inter-American Geodetic Survey during the past decade in extending the South American triangulation to complete the continuous arc from Point Barrow, Alaska, to the southern end of South America.

Likewise, the east-west space surveillance fence, stretching across the United States from Georgia to California rests on the firm foundation of geodetic control provided by the Coast and Geodetic Survey.

Future space craft will be guided more accurately and more reliably because of the previously established geodetic networks which will make possible accurate world-wide radio command and guidance systems.

In addition to demonstrating an almost insatiable appetite for ever increasing levels of geodetic and cartographic precision, our growing space technology offers considerable promise of a host of practical and important benefits to surveyors and mappers. I shall have more to say about these benefits, opportunities, and challenges later.

However, we must not let our zeal for the promise of good things to come or our impatient desire to reap the benefits offered by our growing space capability blind us to the very real, practical, and immediate problems that confront us in attaining these goals. At the heart of most of these problems is the rocket vehicle and its associated communications, tracking and guidance equipment. The rocket vehicle is the essential transportation device for any kind of space activity. It is therefore useful to look briefly at its history, its current status, and its affect on the development of our own space capabilities.

Man's first expression of his conscious desire to engage in space travel is certainly not of recent origin. In fact, the early history of speculation on voyages beyond the bounds of the earth closely parallels the development of concepts about the nature of the universe. As early as the second century Lucian described voyages to the moon, while Kepler speculated on such matters in his "Somnium" published in 1634.

These speculations were first given technical substance and growing hopes of fulfillment at the close of the nineteenth century as the result of work on the dynamics of bodies of variable mass and the principles of

rocket flight by the two now well known Russians, Meshcherskii and Tsiolkovskii. There soon followed, independently, the pioneering work on rockets by Goddard in the United States and Oberth in Germany. In the course of time this pioneering activity attracted the interest of additional workers and beginning in the late 1920's, led to the forming of private technical and scientific groups whose purpose was to cooperate in the systematic study of the new rocket devices. In this early period the work proceeded more or less independently in the three countries and involved little contact between the groups working in the field. During the 1930's and early 1940's the rocket art had progressed to the point where its military potential became apparent and this led to the establishment of substantial Government-sponsored research programs in Germany, Russia, and the United States.

By the early 1940's, but only after the expenditure of considerable effort over a period of some 10 years, the Germans achieved the development of the first practical, automatically guided and controlled rocket vehicle. This was the V-2, a military rocket of about 200 miles range, and it was a major event in the advance of rocket technology. At the close of World War II, both the United States and Russia moved to exploit and further develop the German achievements in rocketry by instituting programs that led to the development of rocket vehicles for use as intercontinental missiles and later adapted these for use as boosters for space vehicles.

During the interval from 1945 to the present time the state of the rocket art in the United States advanced materially in a number of respects. Figure I illustrates this gain in rocket vehicle performance. Today's state of the art makes possible moderately sized single stage rocket vehicles which are capable of ranges more than 3 times greater than the

GROWTH OF SINGLE STAGE ROCKET VEHICLE PERFORMANCE

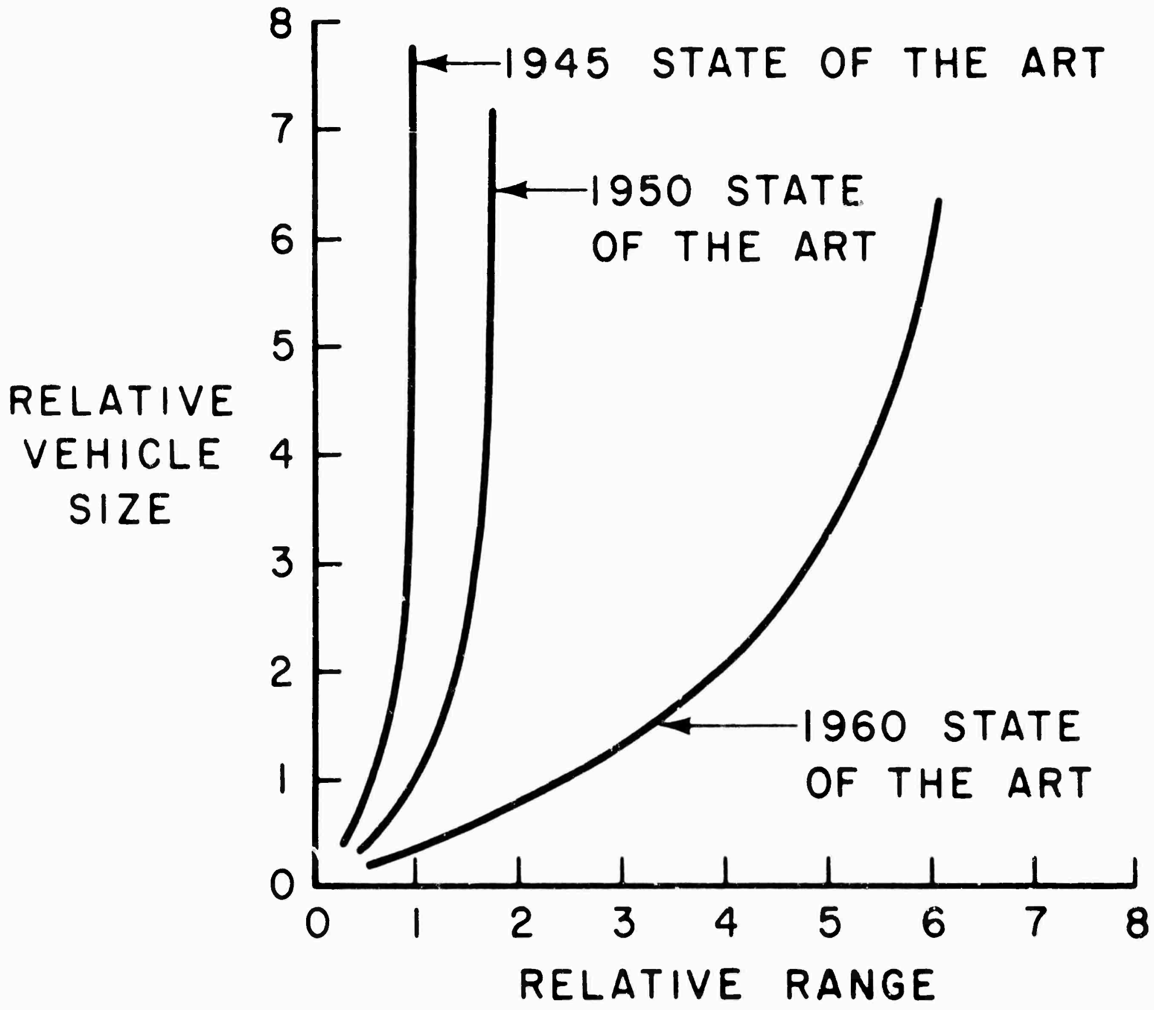

Figure I

maximum possible in 1950 and over 6 times greater than the maximum attainable in 1945.[1,2,3]

Rocket engines have been improved to the point where 95% of the performance theoretically attainable is representative of current practice compared to an efficiency of less than 85% in 1945.[1] Multi-stage rocket vehicles have been developed which have the thrust and endurance necessary to propel payloads over intercontinental distances, an improvement in range by a factor of 30 over the performance attained with the V-2. Improved materials, design techniques, and component miniaturization have reduced the percentage of the rocket vehicle's weight that must be devoted to its structural skeleton and related dead weight by more than a factor of 3, from 25% for the V-2 down to about 6 or 8% for current vehicles.[2] This reduction in the fraction of the rocket vehicle which must be dead weight enables a rocket of a given size today to carry heavier payloads to greater distances than was previously possible.[3] These are substantial technical achievements and have resulted in rocket vehicles which have impressive capabilities, such as the IRBM and ICBM, the now familiar Jupiter, Thor, Atlas, and Titan.

The ballistic missile programs, in addition to providing us with the technological basis for a substantial military capability, also have given us the beginnings of an adequate technological basis for the exploration of our celestial frontier. Here I want to emphasize the word beginnings, principally because in many ways a higher level of performance is required of the rocket vehicle for even the most rudimentary space mission than for ballistic missile use. The velocity performance required of ballistic missiles, satellites and space vehicles is shown in Figure II.[2] The greater velocities required by satellites and space vehicles compared to

VELOCITY REQUIREMENTS FOR BALLISTIC MISSILES, SATELLITES, AND SPACE VEHICLES

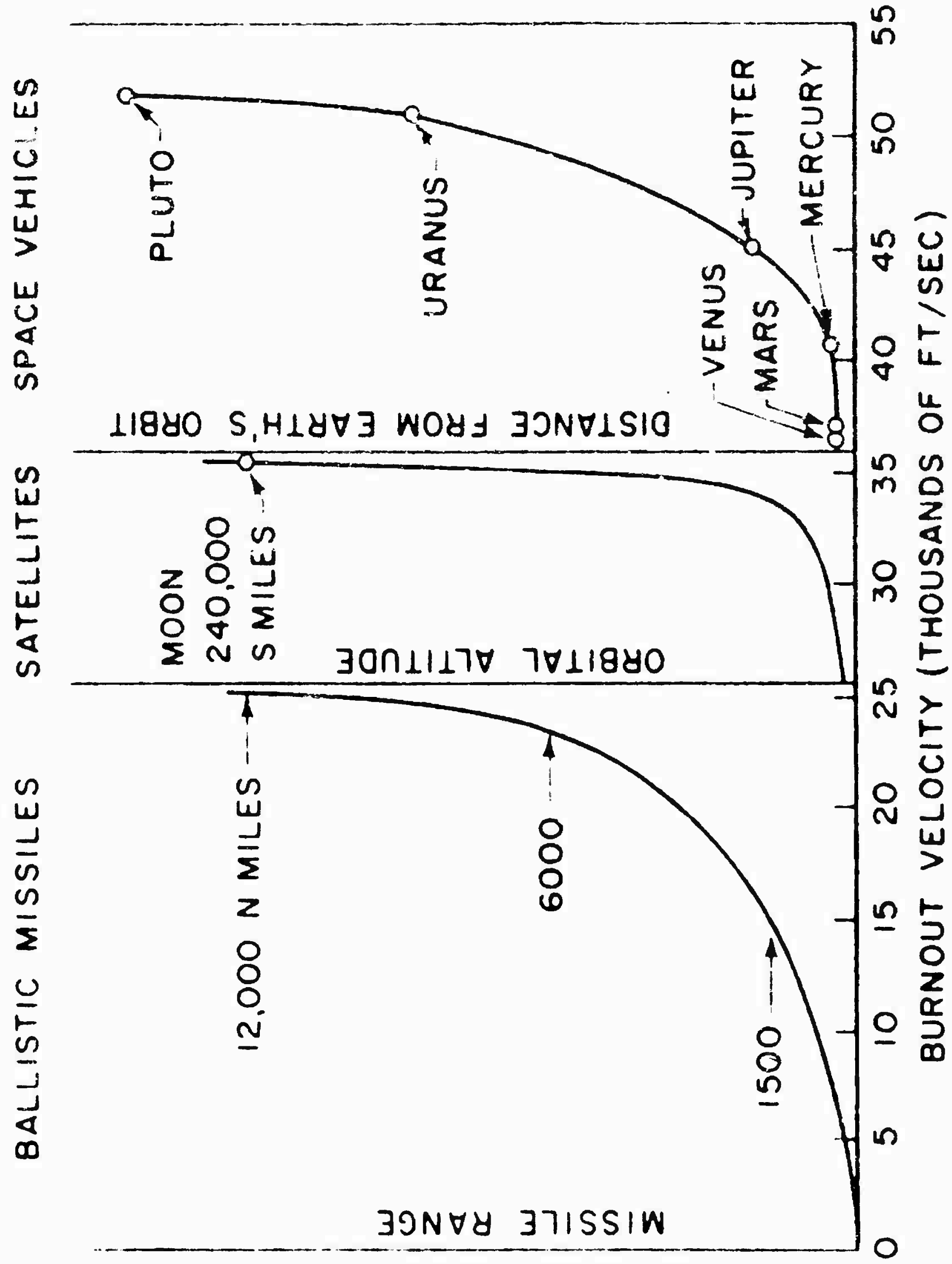

Figure II

ballistic missiles results in the need for more complex vehicles employing a greater number of stages. While the ballistic missile can, and has been used, as the booster stage for space vehicles, properly proportioned upper stages are also needed to exploit the capabilities of the combination. The flight durations of space vehicles are much longer, putting even more stringent demands on the life of space vehicle components. Guidance and control performance levels acceptable for ballistic missiles fall short for some space missions. Controlling the rocket vehicle cutoff velocity to one part in 35,000 will give an impact error at the target of less than one mile in a 6000 mile missile, but would miss Venus by more than 25,000 miles on a ballistic shot at her![2]

We have made good use of the rocket vehicles and components available from the ballistic missile program in our first two years of space exploration and will continue to do so. But it is important to recognize that at this time space activity calls for hard and clever engineering developments that are not yet, in my view, generally appreciated. I also feel that this will remain so for some time to come. We are still very much in the tooling up phase, where the immediate objective is an efficient and reliable rocket vehicle. If we are to engage in space activities on an effective basis, it must be expected that this development of the essential tools of the trade will require a considerable expenditure of resources in terms of funds, manpower, and time.

The first formal step taken by the United States toward the establishment of a program of space exploration was the announcement in 1955 that the President had approved plans by this country for going ahead with the launching of small, unmanned, earth-circling satellites as part of the

United States participation in the International Geophysical Year. In carrying out these plans it was decided to do the work on the smallest significant scale -- more as a demonstration of the feasibility of such activity than as a real start toward a substantial program for the exploration of space.

The dawn of the space age really broke on October 4, 1957 when the Russians placed man's first artificial satellite in orbit around the earth. Since that time the United States has placed 14 satellites in orbit and the Russians an additional two. Further, the United States has launched a series of 4 deep space probes and the Russians 3, with the more spectacular achievements credited to the Russians. In terms of meritorious and substantial scientific results, however, history may well record the 14 satellites and 4 space probes launched by the United States as the more important.

I have already mentioned the improved value for the oblateness of the earth obtained from our satellite data. In addition, our satellite and space probe experiments have led to a better understanding of the propagation characteristics of the ionosphere and its electron density distribution. They have added to knowledge of the earth's magnetic field; they have given us detailed information on cosmic radiation as a function of time and position in space; and they have discovered and roughly outlined the radiation belts that surround the earth. However, even though we have had many successes and have produced much valuable scientific information, our space shots have been overshadowed by the "firsts" and the payload size of those of our only competitor.

The Soviet space exploration program was presumably formally organized in 1954 with the formation of their Interdepartmental Commission for Interplanetary Communication.[4] The course of events since then has proved beyond all doubt that their initial planning called for an aggressive space program which would fully exploit the capabilities of their rocket boosters in the most dramatic fashion possible. In essence, they chose to by-pass the small scale feasibility-demonstration which was our initial step. It has been rightly said that ". . .the side that has the more advanced technology in the way of payload capabilities, guidance and the like will have the distinct edge . . ."[5]

At the present time our national program of space exploration has two parts: first, the use of interim vehicles created on a short-term basis for the limited uses they permit, and second, the development of more versatile and powerful vehicles to provide the basis for a sound program over the long haul.[6] Both of these activities are essential. But maintaining a proper balance between these two is one of the more serious problems facing our nation's space planners today.

To satisfy our immediate needs for space vehicles we are making use of the small upper stage rockets developed for the Vanguard and Jupiter C programs in combination with the IRBM and ICBM vehicles of our military ballistic missile program as boosters. While the resulting vehicle does give us some small capability for beginning to explore our celestial frontier, it by no means exploits the full potential of our IRBM and ICBM rocket vehicles.

The largest scientific payload we have placed in orbit up to the present time is the 142-pound Explorer VI payload launched by a Thor-Able vehicle. This Thor-Able was a space vehicle made by combining a

Thor IRBM booster stage with two small upper stage rockets derived from the Vanguard program, making in all a three-stage vehicle. Somewhat larger payloads have been placed in orbit by the Discoverer satellites of the Department of Defense. However, at the present time, these moderately larger payloads are possible only in low-perigee short-lived orbits which are generally not well suited for many space science experiments.

One useful index of the efficiency of a rocket vehicle is the ratio of its gross takeoff weight to its payload weight. In the case of Explorer VI the ratio is about 750 to 1. On the other hand, as Dr. Homer J. Stewart of the National Aeronautics and Space Administration points out, a properly proportioned three stage vehicle using current levels of technology could have a takeoff weight to payload weight ratio of the order of 40 or 50 to 1.[6] On this basis, our present Thor IRBM as a space vehicle booster is less than 10% effective, not because of its size as a first stage booster rocket, but because we do not now have the properly proportioned upper stages to go with it. The same situation controls the present use of ICBM boosters.

To meet this current deficiency we are now developing two new upper stage rockets, the Agena B and the Centaur. The latter uses a high performance liquid hydrogen and liquid oxygen propellant system and is expected to achieve takeoff weight to payload weight ratios of the order of 30 to 1, a factor of twenty five better than we have been able to accomplish to date. We are also developing the Saturn, a multi-stage rocket vehicle roughly four times the size of the Atlas ICBM. The anticipated growth in size of United States satellite vehicles is shown in Figure III. By 1967, on this schedule, we should be able to launch a satellite having a gross weight in excess of 50,000 pounds, over 350 times the size of Explorer VI, our largest scientific satellite to date.

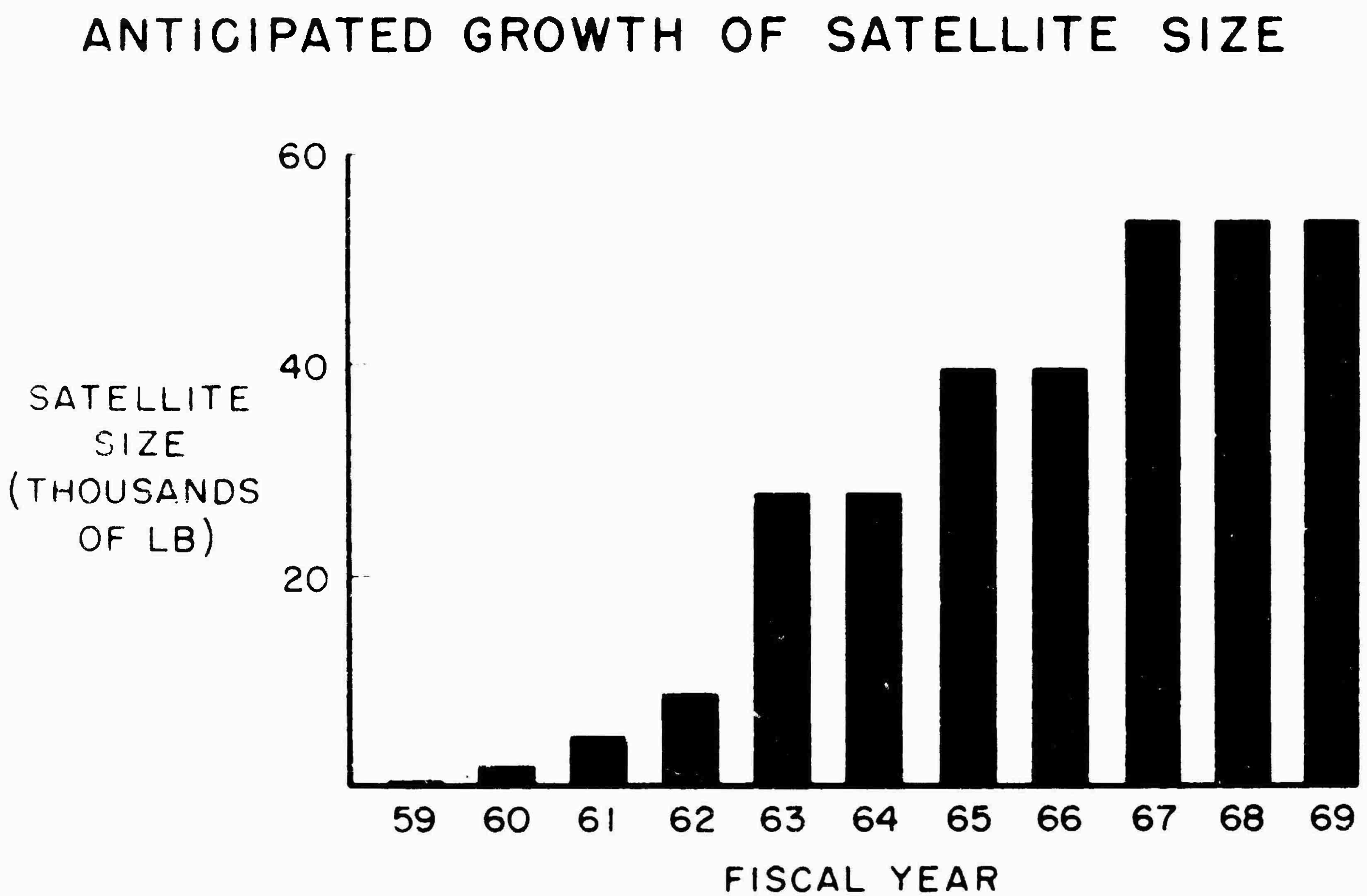
ANTICIPATED GROWTH OF SATELLITE SIZE
SATELLITE SIZE (THOUSANDS OF LB)
60
40
20
59
60
61
62
63
64
65
66
67
68
69
FISCAL YEAR

Figure III

Neither the Centaur nor the Saturn have as yet had their first flight. In fact, of the multi-stage space vehicles flown by the United States up to February, 1960, only Vanguard and Discoverer have test histories of 9 or more launchings. In interpreting this fact it is well to recall that the Germans expended more than 1000 vehicles during the course of the development of the V-2. It is true that we have improved the state of our rocket vehicle technology and our testing and development techniques over the fifteen years from 1945 to the present time; but there is no escaping the fact that the development of big rocket vehicles is an engineering task of truly monumental proportions. That it can be done, and done well, has been proven beyond doubt by our highly successful IRBM and ICBM development programs -- but experience also proves that an extensive flight test program is an integral and necessary part of the job and the only way to get adequate reliability. Referring to Figure IV which is the space vehicle launching program for the next 10 years as presented to the Congress by the NASA last month, it can be appreciated that it will be several years before we can reasonably expect to have achieved the level of rocket vehicle performance and reliability necessary for a significant national advance.

Figure V outlines the Space Administration's program for exploring our celestial frontiers during the coming decade. I think we can feel the professional challenge it presents to us all. All of the activities listed depend in substantial measure upon precise geodetic and cartographic information.

NASA SPACE VEHICLE LAUNCHING PROGRAM

FISCAL YEAR	1960*		1961				62	63	64	65	66	67	68	69
REDSTONE		1	2	3	2									
ATLAS		1	2	1	2	1	6	1						
JUNO II	1		1	3										
THOR-ABLE	2													
ATLAS-ABLE		1	1											
THOR-DELTA	1	1	1	2	1	1	5							
SCOUT		4	2		2		6	6	6	6	6	6	6	6
THOR-AGENA B							1	6	6	6	6	6	6	6
ATLAS-AGENA B					1		3	4	5	6	3	12	12	12
ATLAS-CENTAUR						1	5	4	5	6	9			
SATURN							2	2	3	4	4	4	4	4
NOVA TYPE													1	2
TOTAL	12		29				28	23	25	28	28	28	29	30

*LAST TWO QUARTERS ONLY

Figure IV

NASA MISSION TARGET DATES

CALENDAR YEAR	
1960	FIRST LAUNCHING OF A METEOROLOGICAL SATELLITE
	FIRST LAUNCHING OF A PASSIVE REFLECTOR COMMUNICATIONS SATELLITE
	FIRST SUBORBITAL FLIGHT OF AN ASTRONAUT
1961	FIRST LAUNCHING OF A LUNAR IMPACT VEHICLE
	ATTAINMENT OF MANNED SPACE FLIGHT, PROJECT MERCURY
1962	FIRST LAUNCHING TO THE VICINITY OF VENUS AND/OR MARS
1963–1964	FIRST LAUNCHING OF UNMANNED VEHICLE FOR CONTROLLED LANDING ON THE MOON
	FIRST LAUNCHING ORBITING ASTRONOMICAL AND RADIO ASTRONOMY OBSERVATORY
1964	FIRST LAUNCHING OF UNMANNED LUNAR CIRCUMNAVIGATION AND RETURN TO EARTH VEHICLE
	FIRST RECONNAISSANCE OF MARS AND/OR VENUS BY AN UNMANNED VEHICLE
1965–1967	FIRST LAUNCHING IN A PROGRAM LEADING TO MANNED CIRCUMLUNAR FLIGHT AND TO PERMANENT NEAR-EARTH SPACE STATION
BEYOND 1970	MANNED FLIGHT TO THE MOON

Figure V

On the other hand, satellites and space craft offer the promise of new and valuable techniques for extending our knowledge of the shape and size of the earth. Vanguard I has already contributed a more accurate value of the polar flattening of the earth making possible a better reference ellipsoid for world geodetic datum. In addition, the Army Map Service has been making observations on this same artificial celestial body to aid in a more precise location of islands in the Pacific.

The adaptation of photogrammetric techniques to satellite applications opens an intriguing possibility of areal inventory of resources and surface conditions. Such inventories could perhaps be helpful to wide regional surveys of several kinds: the seasonal advances and retreats of snow cover, ice movements in the oceans, perhaps even vegetation ground cover, and so on.

The value of many of these potential tools is not yet clear and will not be until more actual experience has been obtained with the devices now in development. At present, the main obstacle in testing the worth of these new techniques lies not so much in the satellite-borne devices, but in the availability of launching vehicles having adequate performance and reliability. But it can be predicted with confidence that as soon as adequate launching vehicles do become available, many surveying and mapping uses will be made of them.

The aerial camera has not only contributed to rapid advancement in topographic mapping and charting, but has also aided the discovery of a multitude of hitherto unknown, geological features from the physiography thus made visible. It is not beyond possibility that the wider views afforded from satellites will also reveal important additional geological features yet unrecognized.

In laying plans for leaving the earth to explore our nearest celestial companion, we already feel the need for topographic maps of the moon. Without some better maps, we will be handicapped in any kind of lunar exploration -- manned or unmanned; likewise, with any exploration of the nearby planets. These more distant ventures offer to surveyors and mappers a challenge even more exciting, and I might add even more exacting, than those traditionally met by their professional predecessors who have always pioneered into unknown regions.

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